Executive Summary

Introduction

During the Cold War, the handling of nuclear wastes from weapons-development facilities and naval operations was a classified topic, kept secret to hide the status and readiness of military forces. Beginning with the period of "glasnost," and continuing with the change in the government, information about the handling of nuclear wastes by agencies of the former Soviet Union (FSU) has become available. The principal U.S. Government response to the disclosures of dumping of radioactive wastes directly into the Arctic Ocean and into rivers that drain into the Arctic Ocean was the funding of the Arctic Nuclear Waste Assessment Program (ANWAP) in the Office of Naval Research (ONR). ANWAP supports several diverse projects studying the behavior, transport, and fate of radionuclides in the Arctic Ocean. This report describes an assessment of the potential risks to humans and the environment, particularly in the U.S. Alaskan Arctic, resulting from historic and ongoing FSU military waste-management activities. The assessment was conducted under the direction of the Risk Assessment Integration Group (RAIG), which consisted of several ANWAP investigators.

Scope and Goals of the Assessment

The primary goal of the assessment reported here is to evaluate the health and environmental threat to coastal Alaska posed by radioactive-waste dumping in the Arctic and Northwest Pacific Oceans by the FSU. In particular, the FSU discarded 16 nuclear reactors from submarines and an icebreaker in the Kara Sea near the island of Novaya Zemlya, of which 6 contained spent nuclear fuel (SNF); disposed of liquid and solid wastes in the Sea of Japan; lost a ^{90}Sr-powered radioisotope thermoelectric generator at sea in the Sea of Okhotsk; and disposed of liquid wastes at several sites in the Pacific Ocean, east of the Kamchatka Peninsula. In addition to these known sources in the oceans, the RAIG evaluated FSU waste-disposal practices at inland weapons-development sites that have contaminated major rivers flowing into the Arctic Ocean. The RAIG evaluated these sources for the potential for release to the environment, transport, and impact to Alaskan ecosystems and peoples through a variety of scenarios, including a worst-case total instantaneous and simultaneous release of the sources under investigation.

The risk-assessment process described in this report is applicable to and can be used by other circumpolar countries, with the addition of information about specific ecosystems and human life-styles. They can use the ANWAP risk-assessment framework and approach used by ONR to establish potential doses for Alaska, but add their own specific data sets about human and ecological factors.

The ANWAP risk assessment addresses the following Russian wastes, media, and receptors:

- Dumped nuclear submarines and icebreaker in Kara Sea: marine pathways
- Solid reactor parts in Sea of Japan and Pacific Ocean: marine pathways
- Thermoelectric generator in Sea of Okhotsk: marine pathways
- Current known aqueous wastes in Mayak reservoirs and Asanov Marshes: riverine to marine pathways
- Alaska as receptor

For these wastes and source terms addressed, other pathways, such as atmospheric transport, could be considered under future-funded research efforts for impacts to Alaska. The ANWAP risk assessment does *not* address the following wastes, media, and receptors:

- Radioactive sources in Alaska (except to add perspective for Russian source term)
- Radioactive wastes associated with Russian naval military operations and decommissioning
- Russian production reactor and spent-fuel reprocessing facilities nonaqueous source terms
- Atmospheric, terrestrial and nonaqueous pathways
- Dose calculations for any circumpolar locality other than Alaska

These other, potentially serious sources of radioactivity to the Arctic environment, while outside the scope of the current ANWAP mandate, should be considered for future funding research efforts.

Risk Assessment Technical Approach and Findings

The preparation of this report followed a proven approach of evaluating the potential sources of release and selecting the dominant contributors, predicting the release rates of the dominant contributors into the environment, modeling the transport and deposition of these radionuclides, measuring and estimating their uptake into Arctic fish and marine mammals, and assessing the risks to the biota and humans as a result. This approach predicts the spatial and time scales for currently known and future releases of radioactivity from the source terms under examination, and thus can be used to guide monitoring efforts.

Characterization

The first principal activity for the risk assessment was to characterize the sources of radionuclides in the Arctic seas—not only the FSU sources of interest in the Kara Sea and Northwest Pacific, but potential sources through riverine transport from Russian watersheds to the Arctic Ocean. To place these sources into perspective and to obtain a comprehensive understanding, ANWAP also characterized the already existing fallout levels of key radionuclides, wastes from the Chernobyl incident and European fuel-reprocessing facilities at Sellafield (United Kingdom) and La Hague (France), and naturally occurring radioactivity.

Findings: Except for very localized instances in the Kara Sea near dumped reactors and nuclear-testing sites, the already existing fallout levels and the Sellafield reprocessing source term now dominate in the Arctic.

Radionuclide Screening

The objective of the screening analysis was to identify the most important nuclides for focus from a risk standpoint from the radioactivity sources created by the FSU in the Kara Sea, the Northwest Pacific, and inland along the major Russian river systems.

Findings: The radionuclides that result in over 95% of the potential human and ecological risks are ^{137}Cs, ^{239}Pu, ^{241}Am, and ^{90}Sr. The primary potential risks from the submarine reactor cores in the Kara Sea arise from ^{137}Cs, and the primary potential risks from the land-based sources arise from ^{90}Sr.

Release Scenarios

The radionuclides in the reactors and other wastes dumped into the oceans must first escape from their containers before they can disperse through the environment. Several possible scenarios for future release of these radionuclides were considered for each waste source.

1. **Kara Sea:** Two scenarios were considered for the dumped submarines and icebreaker: (a) a worst-case condition, where a breaching of containment occurs and all of the materials are released instantaneously, and (b) a time-varying best- estimate case, in which the radionuclides are released as the SNF corrodes. Both scenarios were based on the results of the Source-Term Working Group of the International Arctic Seas Assessment Program, sponsored by the International Atomic Energy Agency (IAEA). In the worst case, the total inventory of each radionuclide, about 4,700,000 GBq, is released instantaneously. In the best-estimate case, the maximum Kara Sea release occurs in about the year 2050, after seawater is assumed to enter the unprotected reactor compartments.

   Findings: the total annual release never rises above 1,300 GBq/yr. The rate drops from 1,000 GBq/yr in the year 2100 to 1 GBq/yr in the year 3000. These two scenarios tend to limit the potential impacts.

2. **Sea of Japan and Pacific Ocean, East Coast of Kamchatka:** A worst-case assumption was taken that the dumped reactor solid objects are unenclosed and subject to corrosion, at a corrosion rate of 0.05 mm/yr. Sedimentation cover is assumed to occur by 1,000 years into the future.

   Findings: the total release rate in the Sea of Japan begins at about 1 GBq/yr and drops to less than 0.1 GBq/yr beyond the year 4000; and in the Pacific Ocean releases start below 0.01 GBq/yr over 1,000 years, and fall to 0.000000001 GBq/yr.

3. **Sea of Okhotsk:** Instantaneous release of the 11,000,000 GBq of ^{90}Sr in the radioisotope thermoelectric generator is assumed for analysis.

   Findings: The RAIG assumes that because the RTG is reportedly hermetically sealed and solidly constructed, the radioisotopes will decay before they are released.

4. **West Siberian Basin:** Four scenarios are considered: (a) baseline release based on actual historical record; (b) Mayak reservoir failure releasing all ^{90}Sr within one year; (c) Mayak reservoirs releasing radioactivity to near-surface groundwater under worst-case conditions, and (d) remobilization of ^{90}Sr from the Asanov Marshes, with a one-year release period.

   Findings: The upper bound of the current ongoing baseline release, from global fallout plus past releases from the land-based facilities, is 40,000 GBq/yr of ^{90}Sr; this rate will fall slowly over time with radioactive decay of the sources. All the other possible scenarios result in about the same numerical result, a flux rate of about 1,400,000 GBq/yr for only one year.

Transport Analysis

The next step in the risk assessment was to evaluate the movement of the estimated potential releases of radionuclides in Arctic waters using oceanographic models. A compartmental model was developed, incorporating information from other existing compartmental, ice-ocean, and riverine models. Additionally, the role of sea ice in transport of nuclides was a major focus. Measured historic radionuclide levels in the Arctic Ocean, the Sea of Japan, and areas in the Russian source-term areas were compared with the predicted concentrations from the modeling.

Findings: Sea-ice formation in the Kara Sea is not a likely vehicle for long-range cross-Arctic-basin transport, and total transport by ice via a marine pathway to Alaska would be small. Individual radionuclide characteristics are considered, as well as properties of the marine environment. For example, ^{239}Pu and ^{241}Am will tend to be influenced more by particles and sediments, by becoming bound to them, than will ^{137}Cs and ^{90}Sr. The range of radionuclide concentrations predicted from the model is consistent with those levels measured historically.

Bioconcentration in Food Webs

In addition to actual measurements of radionuclide levels in biota, the radiological risk assessments used bioconcentration factors (BCFs) to extrapolate concentrations of radionuclides in seawater with levels that can be expected in biota over time. Current radionuclide levels in biota and water were measured to determine BCFs that are used in the risk assessment. An international panel of experts determined that BCFs for polar organisms would be the same as or similar to nonpolar, temperate water species. They decided that the factors were sufficiently similar, and confirmed that decades of historical data, as summarized in the IAEA document TecDoc 247-1985, could be used in this risk assessment. BCFs were used to predict uptake of Arctic-disposed radionuclides from the FSU, and of naturally occurring radionuclides, by important dietary species for man, and those that are an important part of food chains leading to man.

Assessment of Risk to Marine Organisms

The RAIG evaluated radionuclide levels in environmental media resulting in significant potential detrimental effects on reproductive success in sensitive Alaskan marine species. We assess the potential for radiological effects by comparing the dose rates predicted using FSU worst-case-release scenarios to our dose-rate no-observable-effects levels (NOELs) for mortality, sterility, and reduced fertility.

Findings: Radionuclides in Alaskan coastal waters and sediments and in selected marine mammals, fishes, and other biota are below levels of concern for bioeffects. Predicted concentrations of radionuclides from FSU sources are not expected to affect survival of reproducing populations of marine mammals, fishes, and other biota of human dietary importance in Alaska. The predicted dose rates are so low in all cases as to make it very unlikely that any loss of endangered species or any significant ecological impacts will occur in areas away from the immediate FSU-disposal sites.

Assessment of Risk to Humans

The RAIG, using available data on subsistence diets, focused on people in north and northwestern coastal Alaska whose subsistence diet includes fish and marine mammals from the Arctic Ocean. The RAIG estimated peak radiation doses for individuals living in a variety of communities and consuming a variety of diets.

Findings: The largest doses to individuals living in Alaskan coastal communities who consume subsistence seafoods come from naturally occurring ^{210}Po, followed by ^{137}Cs and ^{90}Sr from global fallout. The highest predicted doses from FSU sources result from the instantaneous release of radionuclides contained in reactors dumped in the Kara Sea, but these doses are well below background levels and global fallout. The predicted acute and chronic discharges from the Ob and/or Yenisey rivers produce doses similar to the Kara Sea sources.

This report provides a means of estimating individual radiation doses to help interested Alaskan citizens evaluate their own particular circumstances.

Overall Conclusions

Currently, there is no indication that FSU dumping activities caused elevated concentrations of radionuclides in Alaskan waters. To date, the predicted concentrations of radionuclides in Alaskan waters from FSU dumping are so low in all cases that it is highly unlikely that any significant ecological impacts will occur in any areas outside the immediate Russian disposal sites.

The potential human health risks associated with ingesting Alaskan seafoods containing radionuclides derived from the releases evaluated are extremely low. Those wastes pose no threat to human health; Alaska Native communities, therefore, need not alter any of their dietary habits associated with subsistence foods obtained from Alaskan waters.

Recommendations

Since the initiation of funding for ANWAP in 1993 and the risk assessment project for Alaska, which began in 1995, other sources of radioactivity have been identified and warrant international attention, such as Russian naval military activities involving storage, decommissioning, and radioactive-waste management. Source-term data regarding nuclear-weapons production and reprocessing facilities also need refinement.

Monitoring

It should again be reiterated that as far as even the marine sources and pathways that ANWAP investigated, there are gaps in our fully understanding many processes governing transport and ultimate disposition of Russian radioactive materials. The risk assessment bounded the possibilities of exposure through worst-case, total-release assumptions, resulting in dose values below levels of concern for Alaska, across the Arctic Basin from Russia. Nonetheless, it would be valuable to concentrate more effort on biological processes, including migratory patterns and U.S. and other countries' fisheries habits. The ANWAP research revealed a dearth of information regarding radionuclide uptake in Arctic marine mammals. Although it is unlikely that additional information would change the conclusions of this report, more sampling of marine mammals, of organs as well as muscle consumed by residents, would strengthen the ability to predict impacts to biota as well as to man. Concurrent sampling of ocean water would help develop more accurate BCFs. Similar information about uptakes in birds, eggs, and other commonly eaten foods is needed. This research need not be performed only in Alaskan waters—data from other northern countries also would be valuable. Seasonal biogeochemical data also would be valuable from a risk-assessment standpoint.

Source-Term Research

Much of the information available to the RAIG on the Russian inland contamination sources was limited. Research needs include the following: additional international research on the current contents of the FSU fuel-cycle facilities at Krasnoyarsk, Tomsk, and Mayak; the inventories and availabilities of all radionuclides in lakes, holding ponds, and groundwater sources to better define the long-term potential for releases; and better detail on the long-lived, environmentally mobile radionuclides other than the easily detected ^{137}Cs or ^{90}Sr.

Modeling

Shelf-to-slope-to-Arctic-Basin circulation and transport dynamics has just begun to be understood and incorporated into models. Such data sets also are needed for model validation. The experience gained in conducting the assessment for this report shows that there is an opportunity for closer cooperation between assessment modelers and the scientific groups developing ocean-circulation models or performing tracer studies. The various groups involved in research on Arctic contamination should continue to work together to provide integration of ongoing experimental work into useful assessment information.

Other

Additional data on the transport of radioactive materials in the Arctic Ocean could benefit the assessment of numerous other contaminants. Much of the data used in the preparation of this report is of recent origin and needs validation or verification. Particularly important would be more information on Arctic currents: their stability and longevity, influence of wind, and possible seasonal changes.

Although our analyses suggest that ice transport of radionuclides is no major mechanism for moving contamination towards Alaska, it does appear to somewhat increase the transport toward Greenland. If future assessments for other Arctic countries consider the models and techniques developed for this report, more information on the mechanisms of incorporation of sediments and contaminants in ice, and their transport, would be valuable.

The results of this report suggest that the largest impacts would be in the immediate vicinity of the Russian waste dump sites. Future monitoring to evaluate further the sources, locate others, and validate the modeled source terms is suggested.

This report focuses on aquatic sources and foods. It appears that natural background levels of ^{210}Po and radionuclides from global fallout dominate the doses. For a complete perspective, equivalent assessments of the terrestrial pathways for native subsistence life-styles would be beneficial.

This report addresses existing radioactive wastes in the marine environment and ongoing and potential inland releases. Additional sources of radioactivity in the Russian Arctic potentially exist, particularly nuclear wastes associated with Russian naval activities in Murmansk, Vladivostok, and other naval bases. The techniques developed here also could help evaluate the possible impact of hypothetical, or future actual, accidents in those areas.